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Research Article

Experimental Evaluation of Coffee Husk Ash as a Filler in Hot Mix Asphalt Concrete Productions

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The use of coffee husk ash (CHA) as a mineral filler in hot mix asphalt was investigated in this study. Crushed stone dust (CSD) was used as the mineral filler in four distinct serial asphalt concrete samples (5.5%, 6.5%, 7.5%, and 8%) for this purpose. The samples' ideal bitumen content and Marshall stability (MS) value were calculated. The 6.5% filler asphalt series, which has offered the most stability, was picked, and CHA was substituted for it at rates of 25%, 50%, 75%, and 100%. The produced samples were then subjected to an MS test, and the results were evaluated. The effects of mineral filler on the susceptibility of asphalt concrete to moisture were also examined in the present study along with the preparation and evaluation of Marshall stability mixtures with various CHA and bitumen levels. The maintained stability test also evaluates a bituminous mix's capacity to be stripped. The findings indicated that for stability, flow, air voids, VFA, and bulk density, respectively, the optimum asphalt content (5.57%) and filling rate at 75% replacement of crushed stone dust with coffee husk ash had values of 16.820 kN, 4.983 mm, 4.435%, and 73.717%. CHA can be used as long as 75% of the CSD filler material complies with the minimum standards set by the Ethiopian Road Authority and global standards for the manufacturing of hot mix asphalt concrete. The retained stability (RS) test results showed that the retained stability values increased with an increase in bitumen content, indicating that the effect of moisture damage decreases with an increase in asphalt content because a high bitumen content will have a thicker content, which reduces the tendency for the water to percolate into the asphalt mix and cause moisture-related problems.

1. Introduction

Wastes can be used as fillers, admixtures, or in the production of new products. In recent years, trash production from industries such as commerce, agriculture, and other sectors has increased in order to further civilization. The generation of waste materials, which also produces a number of deflections, is primarily what causes environmental contamination. To address this issue, recycling is used in many industries, such as building construction and transportation. Fillers are environmentally friendly particles that are added to materials like plastic, composites, and concrete to improve specific properties of the mix material or to replace the need for pricey binder chemicals. The most commonly used fillers in bituminous mixes are lime, stone dust, and cement. Brick dust, stone dust, concrete dust, limestone dust, fly ash or pond ash, marble dust, rice husk ash, egg shells, and short-fibered asbestos are additional filler elements that can be utilized in bituminous mixes. These substances need to be more refined than a 0.075 mm sieve. The continued rapid growth of the population, as well as the increased demand for transportation, means that the number of vehicles on the road is growing every day, as is the number of axles loads that can be carried. As a result, better highway paving materials are required. A highway pavement's principal purpose is to provide a safe surface for highway cars to travel on. Soil subgrade, subbase course, base course, and surface course are the components of a flexible pavement. One or more layers of the same or slightly different materials and specifications may make up the subbase course, base course, or surface course. Asphalt ingredients are used to coat the surface course. They are common on rural roadways as well as city streets with heavy traffic and poor service. Asphalt concrete is a well-graded mixture of coarse aggregate (50–65%), fine aggregate and filler (35–50%), and asphalt (5–8%) of total aggregate mass [1]. One of the most significant components of asphalt concrete is filler. It affects the characteristics of asphalt concrete [2–4]. Surfaces of this general type that are properly designed and constructed can accommodate nearly unlimited volumes of passenger, mixed, or truck traffic, provided they are supported by suitable foundation structures. The bulk of these surfaces are predicted to have a 20-year or longer economic life.

Construction of hot mix asphalt (HMA) pavements requires large quantities of virgin aggregates and asphalt binder. Hot mix asphalt (HMA) concrete is made of aggregate and asphalt cement. The aggregate serves as the pavement's structural skeleton, and the asphalt cement serves as the mixture's glue. Around 90% of the volume of HMA is mineral aggregate, which includes coarse and fine particles in asphalt paving mixtures. Aggregate quality affects the performance of asphalt pavements in a direct and significant way [5]. Due to its outstanding service performance in providing driving comfort, stability, durability, and water resistance, asphalt concrete is the most extensively used material in pavement [6,7]. Highways are very expensive buildings, so the materials used in their construction must be well-designed. Flexible pavements are built to last for 20 years. As a result, the load distributions that would occur on these structures should be estimated and factored into the design process as well. Current research topics include investigations aimed at improving the performance and longevity of roads. Using various additive materials, it is hoped to improve the performance and lifespan of roadways [8].

Locally available resources include rice husk ash, saw dust ash, sugarcane saw ash, sugarcane bagasse ash, and coffee husk ash. These materials are waste from rice mills, sugar mills, and coffee roasting plants, respectively. They will become major land and air pollutants if they are not adequately controlled. As a result, greater effort is put into waste disposal or recycling. In Uganda, coffee husk is being proposed to be used as a source of energy in the cement production industry, and in Brazil, which is the world's largest coffee producer, using coffee husk as an untreated sorbent for the removal of methylene blue (BM) from aqueous solutions.

Ethiopia produces 4.0 million bags of coffee every year, making it the major African coffee exporter and the tenth largest exporter in the world, with coffee being one of the primary products on the consumer market. Coffee production generates a significant amount of waste, such as husks. As a result, reusing this residue is a viable option for its disposal.

Coffee husks have long been used as a fertilizer, animal feed, and a source of heat during the coffee drying process [9]. Paddy coffee production in Ethiopia has increased in the last decade. Increased cultivation and yield per unit area led to faster production.

Coffee is the second most traded commodity after petroleum and one of the most widely consumed beverages on the planet. Because of the high demand for this product, the coffee industry produces significant amounts of hazardous residues that cause serious environmental issues. The most common coffee industry byproducts are silver skin and wasted coffee grounds, which are obtained during the roasting of beans and the preparation of "instant coffee," respectively. Some attempts have recently been made to employ these residues in the production of brick, ceramic, and mortar, as well as value-added compounds, in order to lessen their toxicity while adding value to them [10]. Coffee, which ranks second only to petroleum in terms of global currency commerce, is vital to the economies of its major producers, including Brazil, Vietnam, Indonesia, Colombia, Ethiopia, India, and Mexico [11]. Coffee husk is commonly regarded as agricultural trash; however, as its volume increases, coffee husk management will become an environmental issue [12].

According to Ref. [13], they evaluated the performance of asphalt mixtures containing rice husk ash (RHA) and wood saw ash (SA) as biomass fillers. For this purpose, Marshall stability, indirect tensile strength, moisture sensitivity, and resilient modulus tests were carried out. The biomass fillers were photographed by X-ray diffraction in order to learn more about biomass particles and to have a better analysis of the test results. Test results revealed that a blend of 25% saw ash and 75% limestone exhibits the best tensile performance, while a blend of 25% rice husk ash and 75% limestone causes greater Marshall stability and less moisture sensitivity.

Researchers have begun incorporating agricultural waste into asphalt pavements in an effort to ease disposal issues, conserve natural resources, facilitate recycling, and enhance pavement performance. A huge volume of agricultural waste called groundnut shell is typically burned to provide electricity or as a disposal method. Reference [14] examined the effect of using groundnut shell ash (GSA) as an asphalt binder modifier on the properties of hot mixed asphalt (HMA).

In terms of the total weight of the asphalt binder, GSA was added to the binder at various concentrations of 5, 10, 15, and 20%. The properties of the modified asphalt binder were assessed using a variety of tests, such as conventional asphalt tests, high temperature storage stability, rotational viscosity (RV), dynamic shear rheometer (DSR), and bending beam rheometer (BBR) tests [14].

According to Ref. [15], the impact of substituting waste materials like fly ash and rice husk ash for hydrated lime, which is typically used as a filler in hot mix asphalt (HMA), First, dense graded bituminous macadam (DBM) mix specimens were created in the lab using varying amounts of HL, RHA, and FA, ranging from 2 percent to 8 percent, in accordance with design mixes created using the Marshall method, and the outcomes were compared to those of a control mix created using 2 percent HL. Through the

Marshall quotient, indirect tensile strength, and tensile strength ratio, the performances of the aforementioned blends were investigated. The investigation's findings point to improved performance of HMA with the addition of RHA and FA, as well as evidence of its economic viability because the optimum bitumen content is decreased by 7.5 percent from that of the control mix when added at a filler ratio of 4 percent. Additionally, RHA exhibits a stronger affinity for bitumen, resulting in the strongest stiffening effect of the bituminous mastic droplets in comparison to that of other fillers utilized, and superior compatibility at the micro level by meeting the necessary criterion. Although a lot of works were conducted about using RHA in many works area, there is no work mentioned in the literature about the use of RHA in the asphalt concrete.

The study in Ref. [16] evaluated the use of fly ash as a fine aggregate replacement in HMA concrete mixtures, and it was obtained from the Soma thermal power plant. The fly ash was added to asphalt concrete mixtures in the range of 5%, 6%, 7%, and 8% of the total mix of the aggregate. The samples were subjected to Marshall testing for stability, bulk specific gravity, voids, flow, and voids in the mineral aggregate found to be optimal. The findings show that mixes made with fly ash have greater stability ratings than combinations made using filler. The mixture containing 5% fly ash had the highest stability value, which was 16.30 kN under ideal conditions. As per Ref. [17], the experimental results showed that the Marshall properties of the specimens constructed with nontraditional fillers (such as slag and rice husk ash) are nearly identical to those of conventional fillers (e.g., stone dust). Slag and stone dust both have the same optimal asphalt content (5.5%), but rice husk ash (5.83%) has a little higher value. According to Ref. [18], the effects of seven industrial waste materials used as mineral fillers in asphalt mixtures were investigated. Rice husk ash (RHA), fly ash (FA), brick dust (BD), marble dust (BD), limestone dust (LSD), and silica fume (SF) were used to create the asphalt mixtures (MD). The experimental outcomes were contrasted with those of normal Portland cement (OPC), a typical mineral filler. The fillers were assessed physically, chemically, and morphologically to see if industrial waste could take the place of the OPC. The density, strength, and durability of the changed asphalt mixtures were examined in order to evaluate their performance. The effects of mineral filler on the susceptibility of asphalt concrete to moisture were also examined in the present study along with the preparation and evaluation of Marshall stability mixtures with various CHA and bitumen levels. The effectiveness of the coffee husk ash waste mineral fillers on the performance of the asphalt concrete has been examined using an integrated experimental technique. The material characterization of each of the four filler rates was done as part of the experimental study. The mechanical performance of asphalt mixtures with various filler content proportions has been assessed. The three main sections of this research study are articulated as follows. In Section 2, the characterization of the bitumen, aggregate, and industrial waste mineral filler as well as the specific experimental strategy are covered. The experimental study's comprehensive findings and analysis are reported in Section 3 in detail. In Section 4, along with information about the study's future focus, the conclusions drawn from the results and the discussion in detail are mentioned.

2. Materials and Methods

2.1. Materials. In this section, the characteristics of the various materials used in the current research are provided. To comprehend how the constituents of asphalt concrete behave, bitumen, aggregates, and mineral fillers have all been thoroughly defined physically and chemically. In this study, the viability of employing waste materials as a filler in asphalt mixtures was examined. The influence of waste materials as mineral fillers for heavy load requirements has been evaluated in the Ethiopian setting, taking into account the pavement.

2.1.1. Aggregates. The qualities of the component materials in hot mix asphalt must meet minimal specifications in order for the material to work satisfactorily. Aggregate is the most important component of HMA, and its quality and physical qualities have a significant impact on mix performance. The quality of aggregates has a significant impact on the road pavement structure's performance and long-term economy. The aggregates also bear the majority of the road's loads and withstand surface abrasion wear. The combined aggregate graduation was chosen to approximate the work mix limits of the graduation provided by AASHTO T27 and T37 [19] for dense graded paving mixtures of surface coarse. In this study, natural aggregates obtained from stone crushers in Addis Zemen quarry site, distinct south Gondar, were used. Different sizes of aggregates, namely, 20 mm, 10 mm, and 6 mm and crushed stone dust with the replacement of coffee husk ash (filler material) were used for the preparation of bituminous mixes. The mix composition and aggregate sieve analysis are reported in Table 1 according to ERA-2013 [20]. The physical requirements of aggregates should meet the desired specifications as specified by American and British standards [21–27], as given in Table 2.

2.1.2. Crushed Stone Dust (CSD) and Coffee Husk Ash (CHA). The engineering properties of bituminous pavement mixtures are greatly influenced by the fillers. The No. 8 sieve is used by the Asphalt Institute (TAI) to distinguish fine material from the filler. The mineral material that passes through a No. 200 sieve is referred to as filler. The filler utilized in this study was coffee husk ash obtained from the Sidama zone of Ethiopia, which was exposed to the sun to remove surface moisture and then burned in an enclosed space to minimize the amount of ash blown off at various temperatures and times. Ethiopian coffee processing companies create large amounts of coffee husk and pulp each year. Nonetheless, these materials have been improperly utilized and preserved or have been discarded in the environment, including water bodies, or have been left to decay or burned in open areas. Regardless, these activities lead to and increase air, environmental, and water pollution. In this experiment, CH was burned at 550 degrees Celsius for three

Table 1: Mix composition and sieve analysis of aggregates.

Grading	1				
Nominal aggregate size	19				
Layer thickness	50–65 mm cumulative % by weight of total aggregate				
IS sieve (mm)	% Passing	ERA specification	% Cumulative Retained	% Used	Wt. Of material (gm)
26.5	—	100	0.00	0.00	0.00
19	97	79–100	3.00	3.00	36.00
13.2	69	59–79	31.00	28.00	336.00
9.5	62	52–72	38.00	7.00	84.00
4.75	46	35–55	54.00	16.00	192.00
2.36	36	28–44	64.00	10.00	120.00
1.18	27	20–34	73.00	9.00	108.00
0.6	20	15–27	80.00	7.00	84.00
0.3	16	10–20	84.00	4.00	48.00
0.15	7	5–13	93.00	9.00	108.00
0.075	4	2–8	96.00	3.00	36.00
Pan	4	—	100.00	4.00	48.00
Total					**1200.00**

Table 2: Physical properties of aggregates.

S. N	Property	Test	Recommended values	Test Method
1	Cleanliness	Grain size analysis	Max 4% passing 0.425 mm	British Standard 1377: part 2 [21]
2	Particle shape	Flakiness Index	Max 35%	British Standard 812: part 105 [22]
3	Strength	Aggregate crushing value (ACV) Aggregate Impact Value (AIV) Los Angeles abrasion value (LAAV)	Max 25% Max 25% Max 30%	British Standard 1377: part 2 [21] ASTM C 131 and C 535 [23, 24]
4	Durability	Soundness test & sodium sulphate	Max 10%	AASHTO T176-86 [25]
5	Polishing	Polished stone value	Min 55	British Standard 812: part 3 [26]
6	Water absorption	Water absorption	Max 2%	British Standard 812: part 2 [27]
7	Stripping	Coating & stripping of bitumen aggregate mix	Minimum retained coating 95%	AASHTO T283 [25]

Table 3: Chemical properties of coffee husk ash (CHA) fillers [28].

Constituents	SiO_2	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	$CaCo_3$	$SiO_2 + Al_2O_3$	$SiO_2 + Al_2O_3 + Fe_2O_3$
% Composition	60.00	3.00	9.52	4.08	1.07	0.08	2.00	2.92	70.00	73.07

hours in a carbonate furnace and was used specific gravity of 2.720. Coffee husk ash is produced after burning coffee husk which is believed to have high reactivity and pozzolanic property. The chemical and physical properties of the employed filler material [28–30] are shown in Tables 3 and 4.

Table 4: Physical properties of CSD and CHA.

S. N	Types of filler	Specific gravity	Test method
1	Crushed stone dust	2.460	ASTM D854 [29]
2	Coffee husk ash	2.720	ASTM D6 [30]

2.1.3. Bitumen. The bitumen used in this study was of 85/100 grade bitumen which is obtained from highway engineering laboratory, Debre Tabor University. The values obtained were compared with the standard specifications as per ERA. The physical properties of bitumen described as per American standards [31–34] are given in Table 5 and the mix should meet the requirements in Table 6 as per given in specification of ERA.

2.2. Mix Design. The Marshall technique of design was created by Bruce Marshall, a former Mississippi Highway Department engineer, and improved by the United States Army Corps of Engineers. The ASTM has standardized the Marshall Test protocols and issued ASTM D1559 [35]. For each type of filler employed, samples of bituminous concrete mixtures were made according to ASTM D1559 at various bitumen concentrations. The suitable graduation aggregates are completely dried and heated as the initial step in the method. A sufficient mixture is prepared at each asphalt level.

A total of 1200 gm of mixture will be required for each specimen. The asphalt and aggregates are then heated

Table 5: Physical Properties of 85/100 grade bitumen.

S. N	Property	Specific limits as per ERA	Test method
1	Penetration at 25°C/100 gm/5 sec, 0.1 mm	85–100	ASTM D5-IP49 [31]
2	Softening points, °C	42–51	ASTM D36 [32]
3	Ductility, cm	>75	ASTM D113-86 [33]
4	Specific gravity, at 27°C	1.02	ASTM D70-97 [34]

Table 6: Requirements for Bituminous pavement layers.

S. N	Property	Specified values	Test method
1	Minimum stability (kN)	7	ASTM D5-IP49 [31]
2	Marshall flow (mm)	2–4	ASTM D36 [32]
3	Air voids (%)	4	ASTM D113-86 [33]
4	Voids filled with bitumen (VFB) %	65–75	ASTM D70-97 [34]

Figure 1: Prepared Marshall samples.

separately before being combined. The slurry is then poured into the mold, hand-mixed with a trowel, and then compacted. A total of 32 samples were prepared at varying bitumen contents of 4%, 5%, 5.25%, 5.5%, 5.75%, 6%, 7%, and 8% for different filler rates (5.5%, 6.5%, 7.5%, and 8.0%). The samples were then tested for stability using the Marshall stability machine as per ASTM *D* 6926–10 [36] and the volumetric properties such as the bulk specific gravity (Gm), theoretical maximum specific gravity (Gt), percent air voids (Vv), percent volume of bitumen (Vb), percent void in mineral aggregates (VMA), percent voids filled with bitumen (VFB), Marshall stability in kN, and flow in mm were worked out. Prepared Marshall samples are shown in Figure 1.

2.3. Experimental Methods. The aim of this research is to investigate the use of coffee husk ash in the hot mix asphalt as a filler material. The percentage replacement of CSD in the hot mix asphalt is 0%, 25%, 50%, 75%, and 100% with various bitumen content levels of 4%, 5%, 5.25%, 5.5%, 5.75%, 6%, 7%, and 8%. These experiments were carried out on bituminous concrete (BC) mixes with filler rates of 5.5%, 6.5%, 7.5%, and 8% that had been considered. The optimum bitumen content was determined using the "Marshall Stability" approach for different filler rates, and then estimated according to maximum Marshall stability. Figure 2 shows the experimental work procedure steps. The volumetric properties of the mix are determined and subsequently calculated for different binder content. These tests were performed in the Highway Engineering Testing Laboratory of Debre Tabor University. In order to perform the laboratory work, Marshall specimens were prepared and tested in accordance with ASTM *D* 6926–10 [36].

2.3.1. Gradation of Aggregates. The gradation of aggregates is the main performance parameter in the job mix design. Based on the gradation, only the voids obtained by the coarser aggregates are filled by the finer aggregates.

2.3.2. Marshall Stability Test (MST). According to ASTM D1559, the Marshall mix method has been used to determine the optimum binder content (OBC) for control mix (CM) and coffee husk ash asphalt mixtures. Marshall samples are created using different binder contents in all combinations. OBC is the computed binder content at the bitumen content corresponding to the midvalue of air voids, the bitumen content corresponding to the highest bulk density, and the bitumen content corresponding to the maximum stability. At OBC, additional Marshall parameters, including stability, flow, voids filled with binder (VFB), voids in mineral aggregate (VMA), and unit weight (UW), are assessed and contrasted with ERA's standard standards.

2.3.3. Retained Stability Test (RST). Retained stability (RS) is a method for determining how moisture-sensitive an asphalt mixture is. For each mix scenario, eight Marshall samples were produced. A conditioned set and an unconditioned set of these samples are separated. Prior to testing, the conditioned samples are cured at 60°C for 24 hours. The air spaces in Marshall specimens (produced at OBC) are conserved

Table 7: Test results of gradation aggregate properties.

S. N	Test description	Lab values	Specification (ERA)
1	Grain size analysis	3.67%	Max 5%
2	Flakiness index	23.99%	Max 30%
	Aggregate crushing value (ACV)	19.64%	Max 25%
3	Aggregate impact value (AIV)	18.88%	Max 25%
	Los angeles abrasion value (LAAV)	17.69%	Max 30%
4	Soundness test (Sodium sulphate)	3.201%	Max 10%
5	Polished stone value	50.90	Min 55
6	Water absorption	0.34%	Max 2%
7	Coating and stripping of Bitumen aggregate mix	99%	Minimum retained coating 95%
	Specific gravity (aggregates)	2.623	—

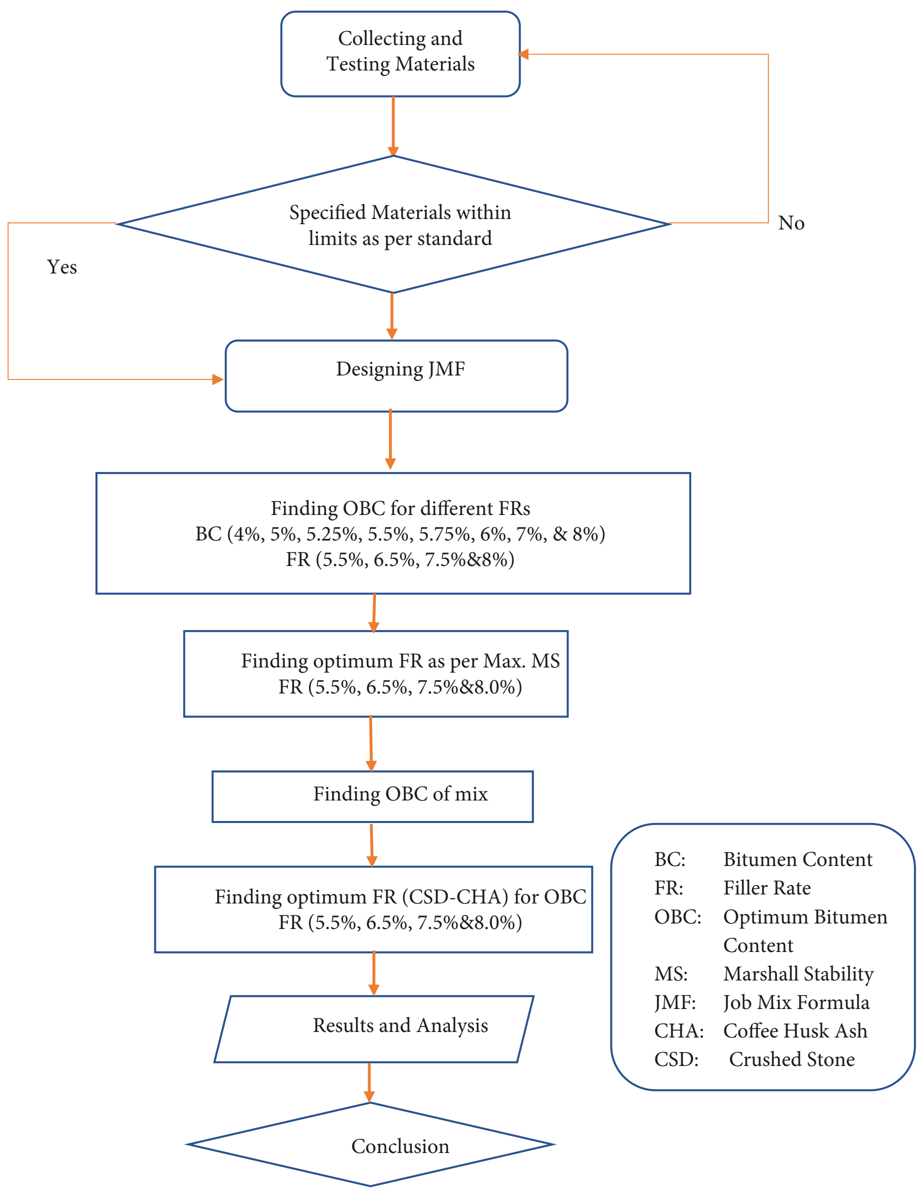

Figure 2: Flowchart of the experimental work.

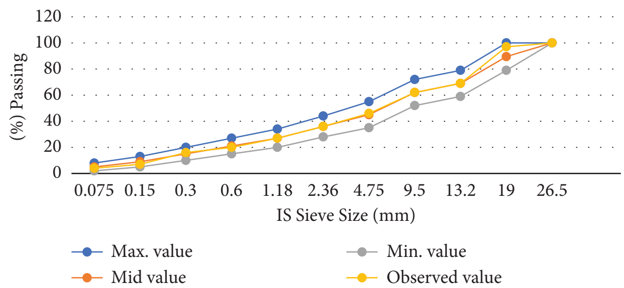

Figure 3: Aggregate gradation of bituminous concrete (BC) mix.

Table 8: Physical Properties of 85/100 grade bitumen.

Property	Lab values	Specific limits as per ERA
Penetration at 25°C/100 gm/5 sec, 0.1 mm	68.67	85–100
Softening points, °C	48	42–51
Ductility, cm	Full scale	>75
Specific gravity, at 27°C	1.002	1.03

Table 9: Volumetric parameters of the AC mix with 5.5% CSD filler.

Asphalt content %	Weight (gm)			Gmb	Gmm	VMA %	VA %	VFB%	Stability (kN)	Flow (mm)
	Wt. in air	Wt. In water	SSD							
4.00	1126	648	1186	2.091	2.304	23.471	9.253	60.576	14.706	2.808
5.00	1127	650	1181	2.121	2.251	23.181	5.761	75.150	13.572	3.627
5.08 *	1131	652	1175	2.163	2.231	21.726	3.069	85.873	15.381	4.536
5.25	1124	650	1179	2.124	2.232	23.275	4.832	79.240	14.193	4.239
5.50	1131	654	1185	2.132	2.233	23.189	4.532	80.458	15.381	4.536
5.75	1132	655	1188	2.125	2.221	23.644	4.331	81.682	22.338	4.788
6.00	1139	662	1198	2.122	2.220	23.954	4.423	81.534	11.223	5.328
7.00	1145	656	1195	2.124	2.182	24.692	2.625	89.368	12.006	5.454
8.00	1145	652	1200	2.088	2.133	26.765	2.132	92.035	9.090	5.346

when samples for a retained stability test are created. All samples are tested using the Marshall Apparatus at a loading rate of 50 ± 5 mm. The flowchart summarizing the experimental study was illustrated in Figure 2.

3. Results and Discussion

3.1. Aggregates. The physical properties of the aggregates were tested before bringing them into use and results indicate that the aggregate meets ERA-2013 specification requirements for BC. It was found that the aggregates used for this study all conform within the permissible limits as specified in ERA pavement design manual specifications. The results obtained are given in Table 7.

3.2. Gradation of Bituminous Mix. The gradation used in this study for a bituminous concrete mix (BC) according to ERA specifications was found to be between the upper and lower gradation limits as shown in Figure 3.

3.3. Bitumen. In Ethiopia, 85/100 PG bitumen is widely used and suitable for temperature and weather conditions. The values obtained from the penetration test, softening test, and ductility test were compared with specific values as per ERA and were found to satisfy the requirements as specified. The results are given below in Table 8.

3.4. Marshall Stability Test (MST). The Marshall mix method is used to determine the asphalt mixture's optimal binder content (OBC). The Marshall parameters are listed in through Tables 9–12 for various mixtures. The relationship between filler content and Marshall properties of mixes were examined with MS altering with crushed stone dust in proportions of 25%, 50%, 75%, and 100%, and the findings were evaluated. The optimal asphalt content for CSD filling rates of 5.5%, 6.5%, 7.5%, and 8.0% was determined to be 5.08%, 5.57%, 5.55%, and 5.35%, respectively. As a result of this experiment, Marshall samples containing 6.5 percent crushed stone dust had higher bitumen concrete mix stability, flow, and other volumetric attributes that were within an ERA specification limit. The effects of substituting coffee husk ash (CHA) for various proportions of the filler rate on the Marshall stability, flow, and volumetric properties of standard binder course asphalt concrete are investigated. Crushed stone dust filler was substituted with the CHA filler in four increments of 25%, 50%, 75%, and 100% by weight, as stated in Table 13, based on establishing the quantity of optimum bitumen content of 5.57% and optimum filler rate content of 6.5%.

Table 10: Volumetric parameters of the AC mix with 6.5% CSD filler.

Asphalt content %	Weight (gm)			Gmb	Gmm	VMA %	VA %	VFB%	Stability (kN)	Flow (mm)
	Wt. in air	Wt. In water	SSD							
4.00	1220	701	1238	2.271	2.496	16.883	8.995	46.719	15.932	3.042
5.00	1221	704	1235	2.299	2.438	16.735	5.734	65.737	14.703	3.929
5.25	1218	704	1233	2.302	2.418	16.845	4.805	71.475	15.376	4.592
5.50	1226	709	1239	2.312	2.419	16.705	4.437	73.438	16.663	4.914
5.57 *	1226	709	1240	2.309	2.416	16.874	4.435	73.717	16.820	4.983
5.75	1227	710	1243	2.300	2.406	17.356	4.403	74.633	24.200	5.187
6.00	1233	717	1253	2.299	2.405	17.611	4.401	75.009	12.158	5.772
7.00	1240	711	1250	2.300	2.363	18.452	2.684	85.454	13.007	5.909
8.00	1240	706	1254	2.263	2.311	20.627	2.078	89.924	9.848	5.792

Table 11: Volumetric parameters of the AC mix with 7.5% CSD filler.

Asphalt content %	Weight (gm)			Gmb	Gmm	VMA %	VA %	VFB%	Stability (kN)	Flow (mm)
	Wt. in air	Wt. In water	SSD							
4.00	1188	683	1220	2.213	2.432	19.006	8.991	52.693	15.523	2.964
5.00	1189	686	1217	2.240	2.376	18.872	5.743	69.570	14.326	3.829
5.25	1187	686	1215	2.243	2.356	18.977	4.814	74.632	14.982	4.475
5.50	1194	691	1221	2.252	2.357	18.866	4.469	76.314	16.236	4.788
5.55 *	1194	691	1223	2.244	2.354	19.197	4.658	75.738	16.369	4.855
5.75	1195	692	1225	2.241	2.345	19.476	4.439	77.210	23.579	5.054
6.00	1202	698	1234	2.243	2.344	19.618	4.290	78.134	11.847	5.624
7.00	1208	693	1232	2.240	2.303	20.579	2.725	86.761	12.673	5.757
8.00	1208	688	1236	2.204	2.252	22.696	2.096	90.764	9.595	5.643

Table 12: Volumetric parameters of the AC mix with 8.0% CSD filler.

Asphalt content %	Weight (gm)			Gmb	Gmm	VMA %	VA %	VFB%	Stability (kN)	Flow (mm)
	Wt. in air	Wt. In water	SSD							
4.00	1157	665	1202	2.155	2.368	21.128	8.987	57.464	15.115	2.886
5.00	1158	668	1199	2.180	2.313	21.045	5.752	72.669	13.949	3.728
5.25	1155	668	1197	2.183	2.294	21.144	4.823	77.190	14.587	4.357
5.35 *	1163	672	1196	2.219	2.295	19.928	3.291	83.484	15.808	4.662
5.50	1163	672	1203	2.192	2.295	21.028	4.500	78.599	15.808	4.662
5.75	1164	673	1206	2.185	2.283	21.488	4.295	80.012	22.959	4.921
6.00	1170	680	1216	2.183	2.282	21.768	4.357	79.987	11.535	5.476
7.00	1177	674	1213	2.184	2.242	22.565	2.585	88.546	12.340	5.606
8.00	1177	670	1218	2.146	2.192	24.730	2.114	91.452	9.343	5.495

* OBC : optimum bitumen content.

Table 13: Asphalt concrete mixtures prepared by using different filler rates for 6.5% CSD.

Samples name	Aggregates			Filler (CSD + CHA) %	CSD %	CHA %
	20 mm	10 mm	6 mm			
Control sample	42.75	17.25	33.5	6.50(100)	6.500(100)	0.000 (0)
*** CHAAC1**	**42.75**	**17.25**	**33.5**	**6.50(100)**	**1.625 (25)**	**4.875 (75)**
CHAAC2	42.75	17.25	33.5	6.50(100)	3.250 (50)	3.250 (50)
CHAAC3	42.75	17.25	33.5	6.50(100)	4.875 (75)	1.625 (25)
CHAAC4	42.75	17.25	33.5	6.50(100)	0.000 (0)	6.500 (100)

* CHAAC : coffee husk ash asphalt concrete.

Figure 4 shows that as the asphalt amount raised, the Marshall stability mix value climbed until it reached a maximum of 24.20 kN at 75 percent of coffee husk ash content. It began to deteriorate beyond this point. For high traffic, the flow value limit must be a minimum of 2 mm and a maximum of 4 mm ERA-2013 [20]. The flow of 75% CHA

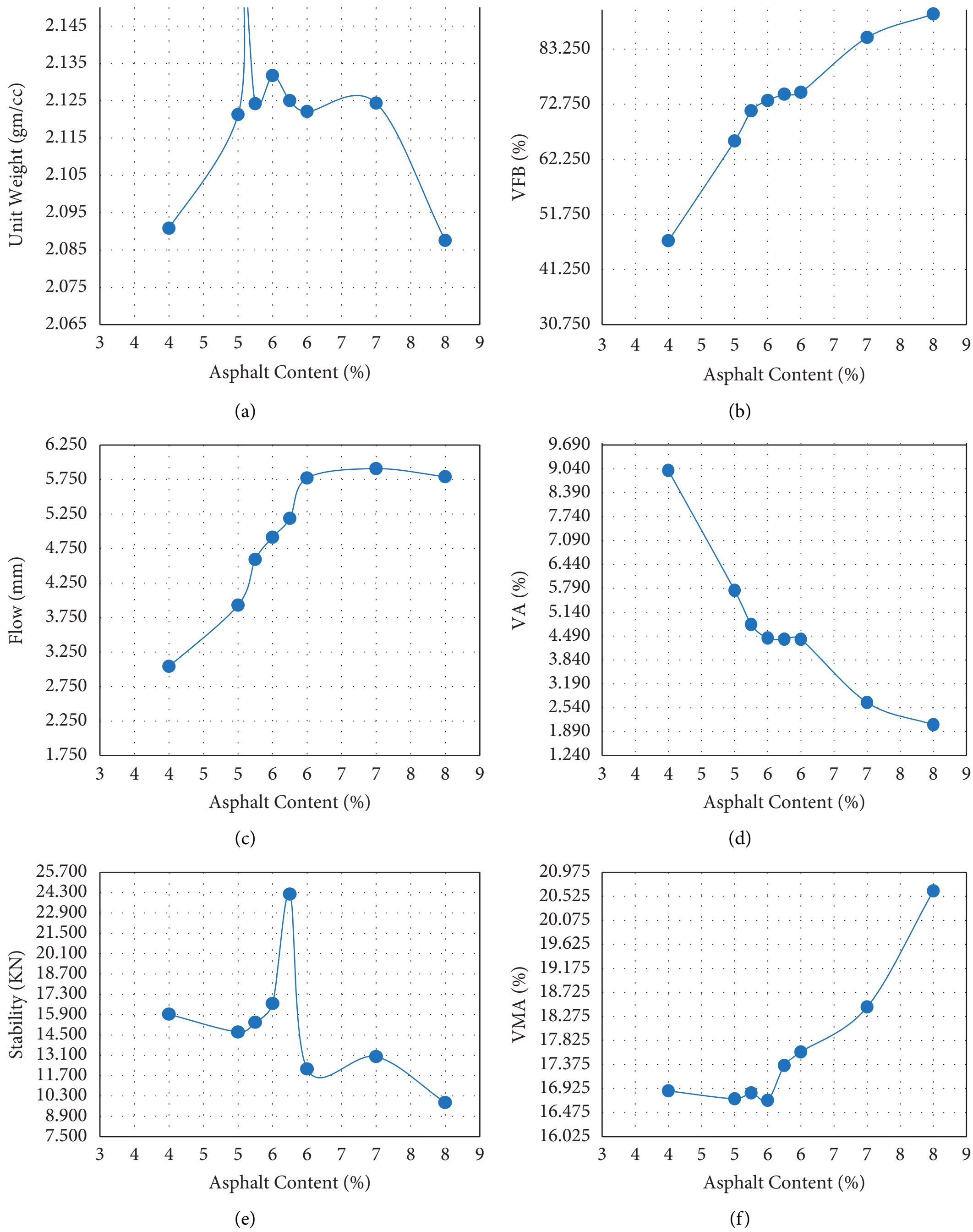

Figure 4: Marshall properties vs. asphalt contents for specimens prepared with CHA as filler (a–f). (a) Asphalt content vs. unit wt. (b) Asphalt content vs. VFA. (c) Asphalt content vs. flow values. (d) Asphalt content vs. air voids (VA). (e) Asphalt content vs. stability. (f) Asphalt content vs. VMA.

(1.625% CSD and 4.875% CHA) filler rate value was 4.983 mm. It means that at all replacement rates, the value was within the range of the ERA Pavement Design Manual standards.

Figure 4 depicts the relationship between the ash concentration of coffee husks and the holes in mineral aggregates. The gaps in mineral aggregates reduce with increasing coffee husk ash content until they reach a minimum value, after which they raise. In asphalt samples prepared using 1.625% CSD and 4.875% CHA, the minimal VMA value is 16.263%. The value of voids in mineral aggregates is entirely within the ERA Pavement Design Manual specification's permitted limits. According to the Ethiopian Road Authority (ERA) [19], the results of Marshall parameter values of 2.309 gm/cc, 73.72%, 4.98 mm, 4.435%, 16.82 kN, and 16.87% were unit weight, VFB, flow value, air voids, stability, and voids in mineral aggregates, respectively, as shown in Figure 4. They meet the standard specification limits. The Marshall stability, flow values, and volumetric properties of asphalt concrete mix at filling rates of 5.5%, 6.5%, 7.5%, and 8.0% with bitumen content are shown in Tables 9–12, respectively.

Table 14: Job mix formula (JMF) properties at 5.57% OBC and 6.5% filler rate.

Properties	Results	Specification	Test methods	Remark
Marshall stability (kN)	16.820	Min 7	ERA	
Marshall flow (mm)	4.983	2–4	ERA	
Air voids (%)	4.435	3–5	ERA	
Unit wt. (g/cc)	2.309	-	ERA	Ok!
VFB %	73.717	65–75	ERA	
VMA %	16.874			
Optimum asphalt content (%)	5.57	4–6	ERA	

Table 15: Retained stability values of different bitumen content.

Asphalt content %	Stability (kN)		Retained stability (RS) %
	Standard	Conditioned	
4.00	17.87	12.95	72.468
5.00	15.91	12.47	78.378
5.25	16.79	14.27	84.991
5.50	18.5	16.15	87.297
5.57 *	20.21	17.91	88.619
5.75	25.15	22.95	91.252
6.00	13.92	13.05	93.750
7.00	11.75	11.51	97.957
8.00	9.15	9.01	98.470

3.5. Optimum Bitumen Content (OBC). The National Asphalt Pavement Association (NAPA) was utilized in this study to calculate the optimum asphalt content (OAC). Because this method requires the preparation of plotting curves, plots were made based on this, as shown in Figure 4. The optimum bitumen content is determined from the following graphs plotted in Figure 4:

(i) Bitumen content corresponding to maximum stability
(ii) Bitumen content corresponding to maximum bulk density
(iii) Bitumen content corresponding to the mean of designed limit of percent air voids (Vv) in the total mix

From Figure 4, the bitumen content corresponding to maximum stability, bitumen content corresponding to maximum bulk density, and bitumen content corresponding to midvalue of air voids and are 5.75%, 5.50%, and 5.46%, respectively. Therefore, optimum bitumen content (OBC) is the average of the three bitumen contents (i.e., $(5.75 + 5.50 + 5.46)/3 = 5.57\%$)). The Marshall stability, flow value, and volumetric properties of HMA at OBC and optimum flow rate are summarized in Table 14 and are shown in Figure 4.

3.6. Moisture Sensitivity Test. The retained stability (RS) test was used in this study to assess the moisture susceptibility. To ascertain a bituminous mixture's moisture susceptibility properties, Ethiopian requirements (ERA-2013) call for the maintained stability test.

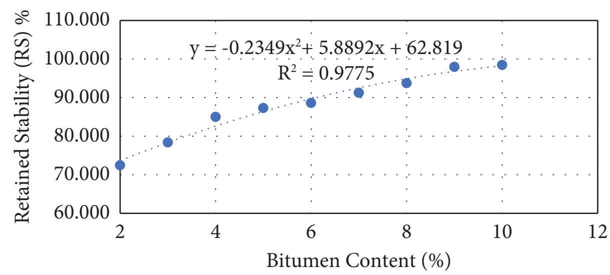

Figure 5: Retained stability (RS) of bitumen content (BC).

3.6.1. Retained Stability Test. The bituminous mix's ability to be stripped is determined by the retained stability test. This test is carried out in accordance with ERA-2013 specifications and the Standard Test Procedures Manual. Retained stability values of different bitumen content are tabulated in Table 15, and the moisture susceptibility value of retained stability values are shown in Figure 5.

Figure 5 displays the maintained stability for several mixtures that were made for bitumen contents of 4%, 5%, and 5.25%, 5.5%, 5.75%, 6%, 7%, and 8% and tested for Marshall stability in both unconditioned and conditioned conditions. The retained stability (RS) test results showed that retained stability values increased with an increase in bitumen content. This means that the effect of moisture damage decreases with an increase in asphalt content because high bitumen content will have a thicker content, which reduces the tendency of the water to percolate into the asphalt mix, which can cause moisture-related problems.

4. Conclusion

The following conclusions can be drawn from the study:

(1) The optimum bitumen content (OBC) was discovered to be 5.57%, which can produce a long-lasting bituminous concrete mixture. The flow value was 4.983 mm, and the VFB was 73.717% for OBC of 5.57%. For the bituminous concrete (BC) mix, all of these qualities meet the ERA criteria.
(2) According to test results, mixes that contained 75% CHA and 25% CSD of FR (corresponding to FR 4.875% CHA and 1.625% CSD) had the best MS when measured in terms of MS.The MS chart made it evident that MS values climb to a certain point and then fall after that point in Figure 4.

(3) The mixture showed maximum stability, maximum bulk density, and VA within the permitted range of the standard specifications after crushed stone dust replacement with coffee husk ash was 75 percent. As a result, for areas with heavy traffic, the percentage content of coffee husk at 75% by weight of crushed stone dust (CSD) filler or containing 4.875 percent by weight of aggregate can be most effective.

(4) The retained stability tests (RST) showed that the retained stability values increased with an increase in bitumen content, indicating that the impact of moisture damage decreases with an increase in asphalt content because a high bitumen content will have a thicker content, which reduces the tendency for the water to percolate into the asphalt mix and potentially cause moisture-related issues.

This study needs to be expanded by performing rutting and fatigue analyses in order to employ these fillers in the field in future research. An indirect tensile strength test and a tensile strength ratio test (TSR) can be carried out and is advised in order to understand the field behavior because all studies have been carried out at the laboratory size.

Data Availability

The data that support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interests regarding the publication of this paper.

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